On the Implementation of Hierarchy in the Ventral Visual Pathway

Stuart Geman

- Introduction
- Some experiments from Clay Reid's lab
- Nonlinearity, functional connectivity, functional common input
- Invariance and functional common input
- Experiments of Polsky, Mel, & Schiller
- Experiments of Palanca and DeAngelis
- Computer experiments
- Topological representation

Introduction

- **Compositions of reusable parts (hierarchical representation)**
  - **Anatomical/physiological evidence**
  - **Compositionality – productivity and systematicity**
  - **Computation: fine-to-coarse *representation* yields coarse-to-fine *computation***
  - **Performance:**
    - **Curse of compositionality: backgrounds made of the same stuff**
    - **Blessing of compositionality: objects come equipped with their own background models**
- **The mystery of invariance in biological vision**
  - **Invariant representations are poor building blocks**
  - **Dilemma of invariance vs selectivity**

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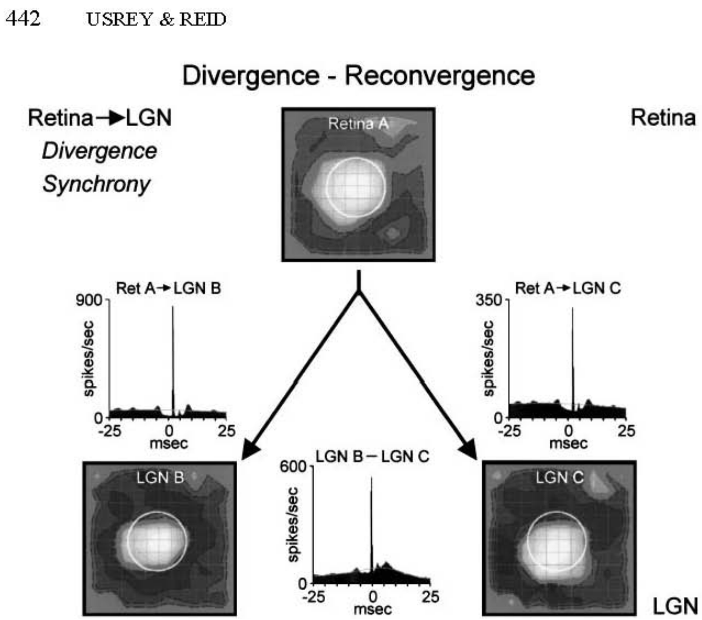
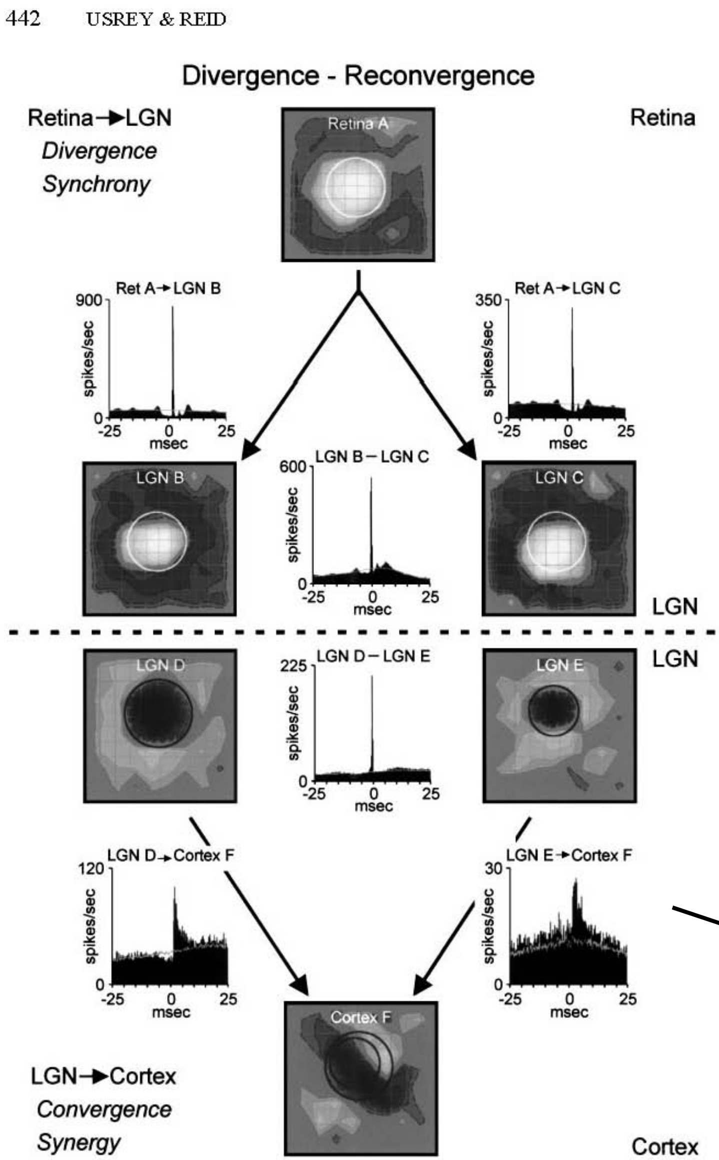
Some experiments from Clay Reid’s lab



ganglion cells

up to 40% spikes <1ms synchrony

Some experiments from Clay Reid's lab



ganglion cells

up to 40% spikes <1ms synchrony

Reid: special to retina-cortex connection

too many cortical-cortical synapses (single events irrelevant)

<1ms correlation

⇓

~70% more effective in generating spike

V1 simple cell

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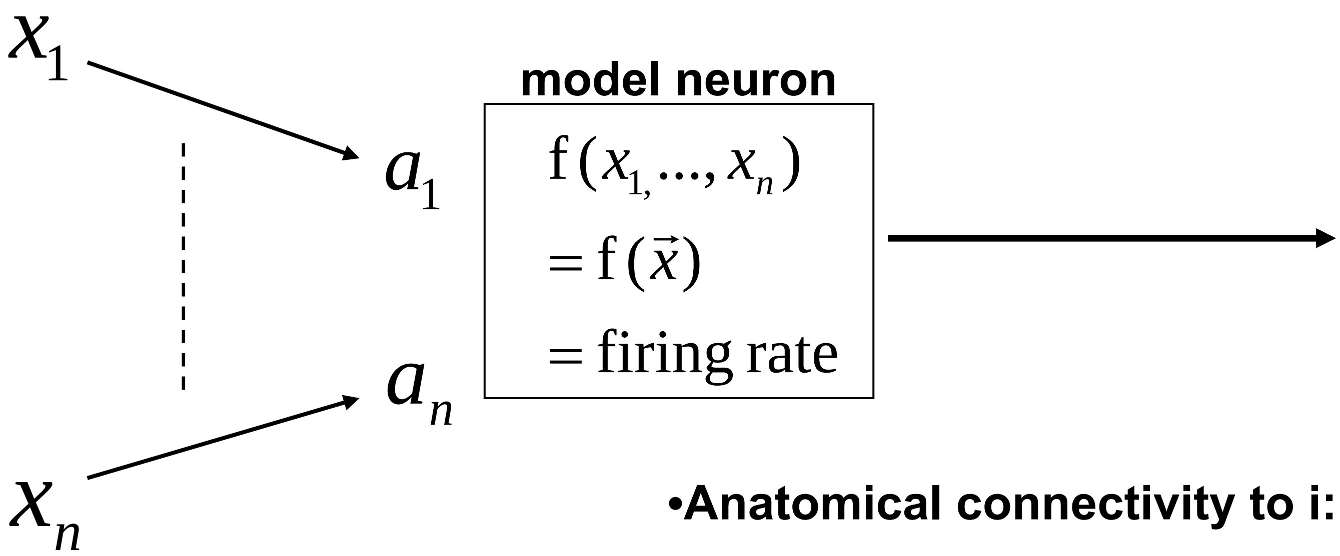
Nonlinearity, functional connectivity, functional common input



- **Anatomical connectivity to i:** a_i
- **<u>Functional</u> <u>connectivity</u> to i:** $\frac{\partial f}{\partial x_i}(\vec{x})$

FC =
- **<u>Constant</u> if f linear**
- **Function of $\vec{X}$ if f nonlinear**

e.g saturation

e.g. invariance (FC to target pattern!)

Conclusion:

FC ≠ AC

FCI ≠ ACI

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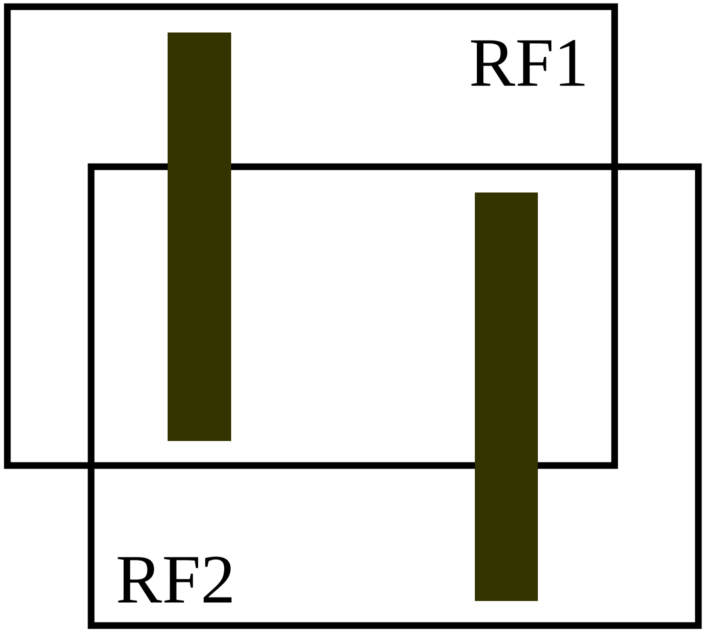
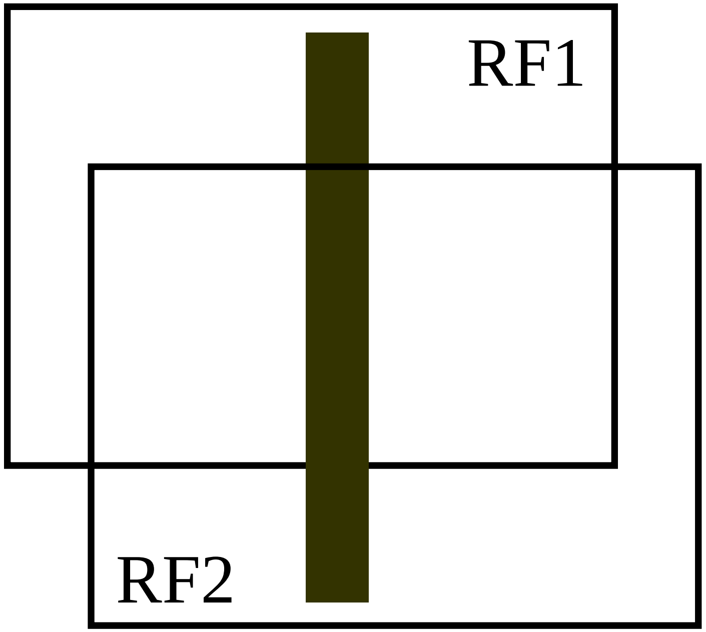
Invariance and functional common input

What circumstances promote Functional Common Input (FCI)?

Example:



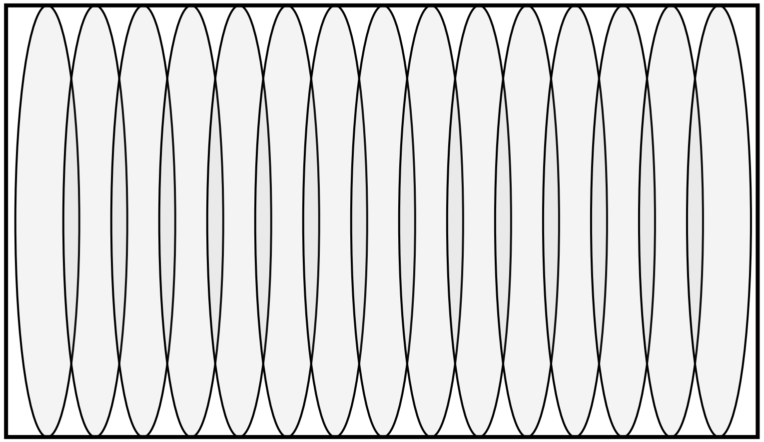


- **High ACI**
- **Low FCI**

- **Low ACI**
- **High FCI**

Invariance and functional common input

More formally: consider generalization of "energy model" (Adelson & Bergen, Poggio & Riesenhuber, Amit & D. Geman)



$\vec{a}^{\,1}$ - - - - - - - - - - $\vec{a}^{\,m}$

$$\mathrm{f}(x_1,\ldots,x_n) = \sum_{\lambda=1}^{m} (\vec{a}^{\,\lambda} \cdot \vec{x})^p$$

p large =>

- $\mathrm{f}(x_1,\ldots,x_n) \approx (\vec{a}^{\,\lambda^*} \cdot \vec{x})^p$ (where $\vec{a}^{\,\lambda^*}$ achieves max)
- $\dfrac{\partial \mathrm{f}}{\partial x_i}\mathrm{f}(x_1,\ldots,x_n) \approx p(\vec{a}^{\,\lambda^*} \cdot \vec{x})^{p-1}\, a_i^{\lambda^*}$

$= 0$ away from maximizing filter

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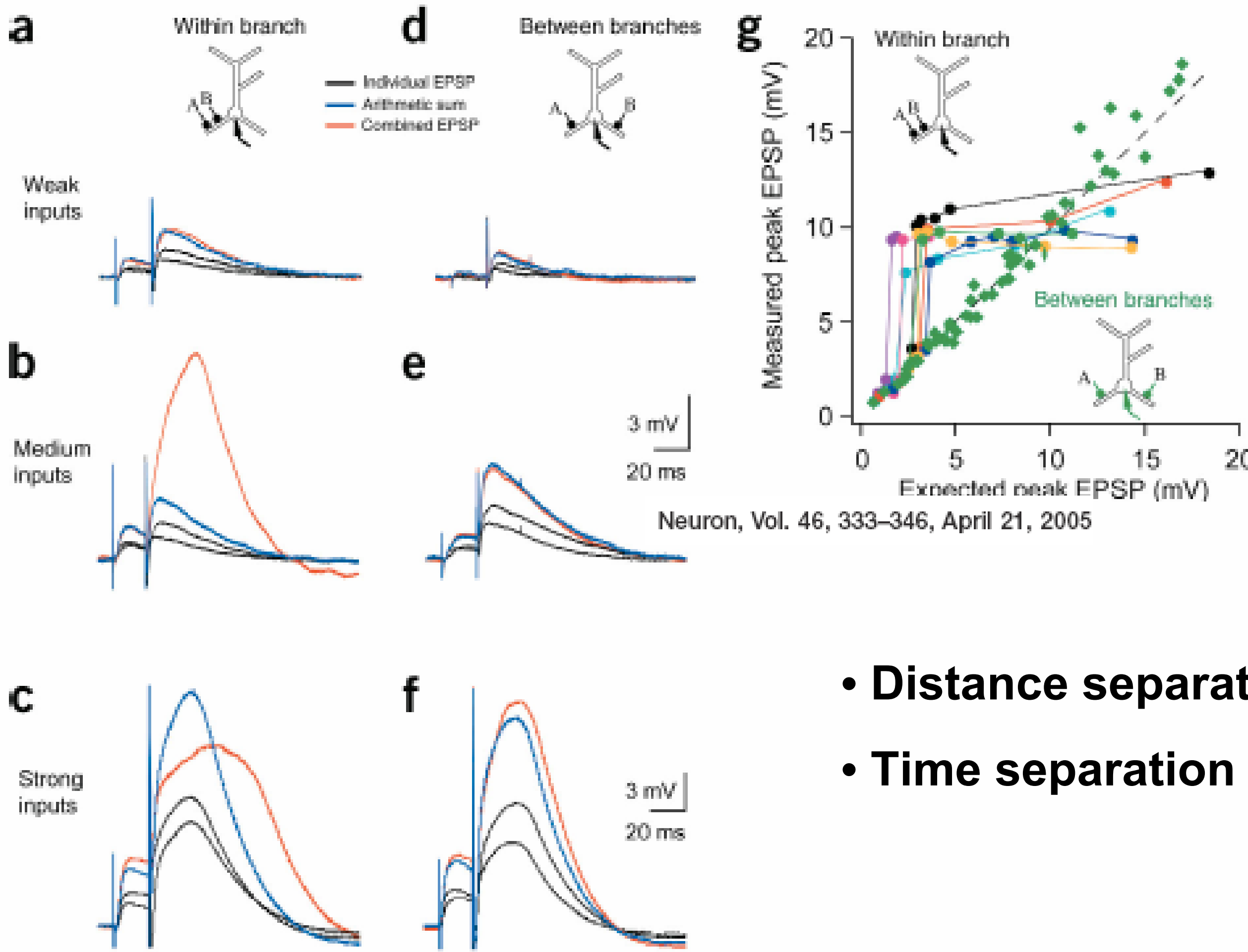
Experiments of Polsky, Mel, & Schiller

Rat slice, layer 5 pyramidal cells



Neuron, Vol. 46, 333–346, April 21, 2005

Nature Neuroscience, Vol. 4, 2005

- **Distance separation < 40 microns**
- **Time separation < 40 ms**

Point: consistent with

$$\mathrm{f}(x_1,\ldots,x_n) = \sum_{\text{branches: } \lambda=1}^{m} (\vec{a}^{\lambda} \cdot \vec{x})^{p} \qquad p > 1$$

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Experiments of Palanca and DeAngelis

Multi-unit recordings from MT of fixating macaque monkeys

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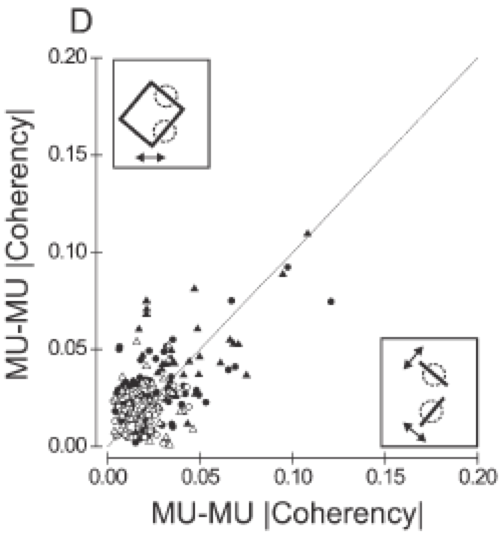

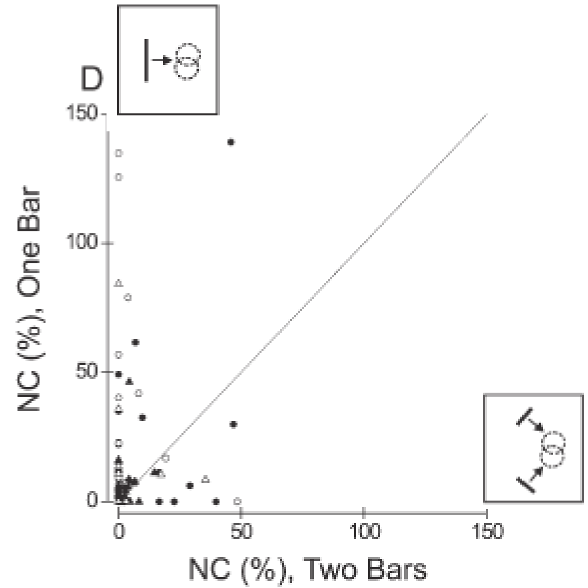

- "…may simply be a reflection of local cortical connectivity…"
- "…synchrony has a limited role in feature grouping that is restricted to overlapping and/or collinear RFs."

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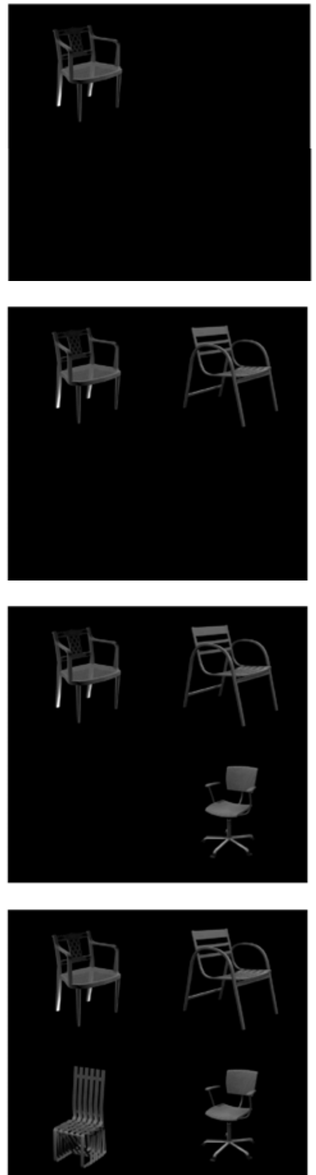
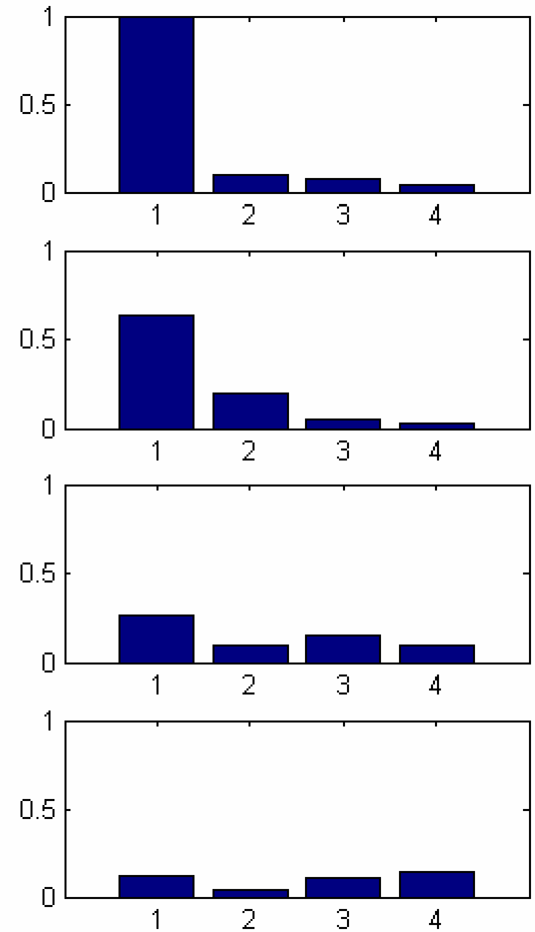
Computer experiments

Some experiments by Anastasia Anishchenko

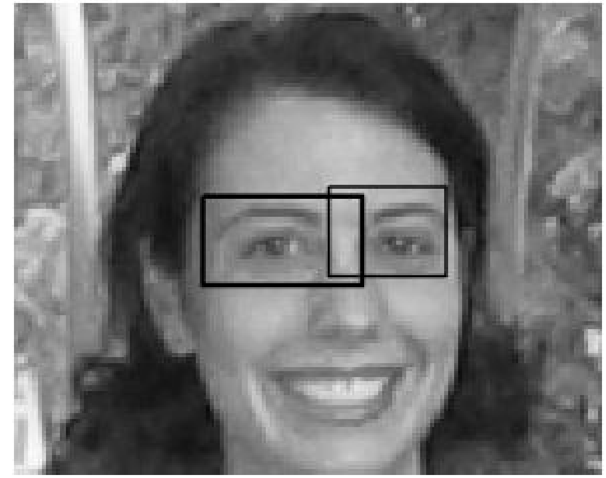
HMAX
Recognition
Performance





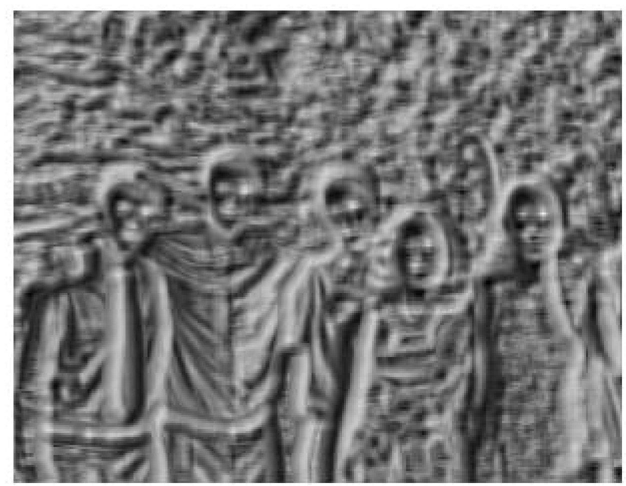
Computer experiments

(a)
original image



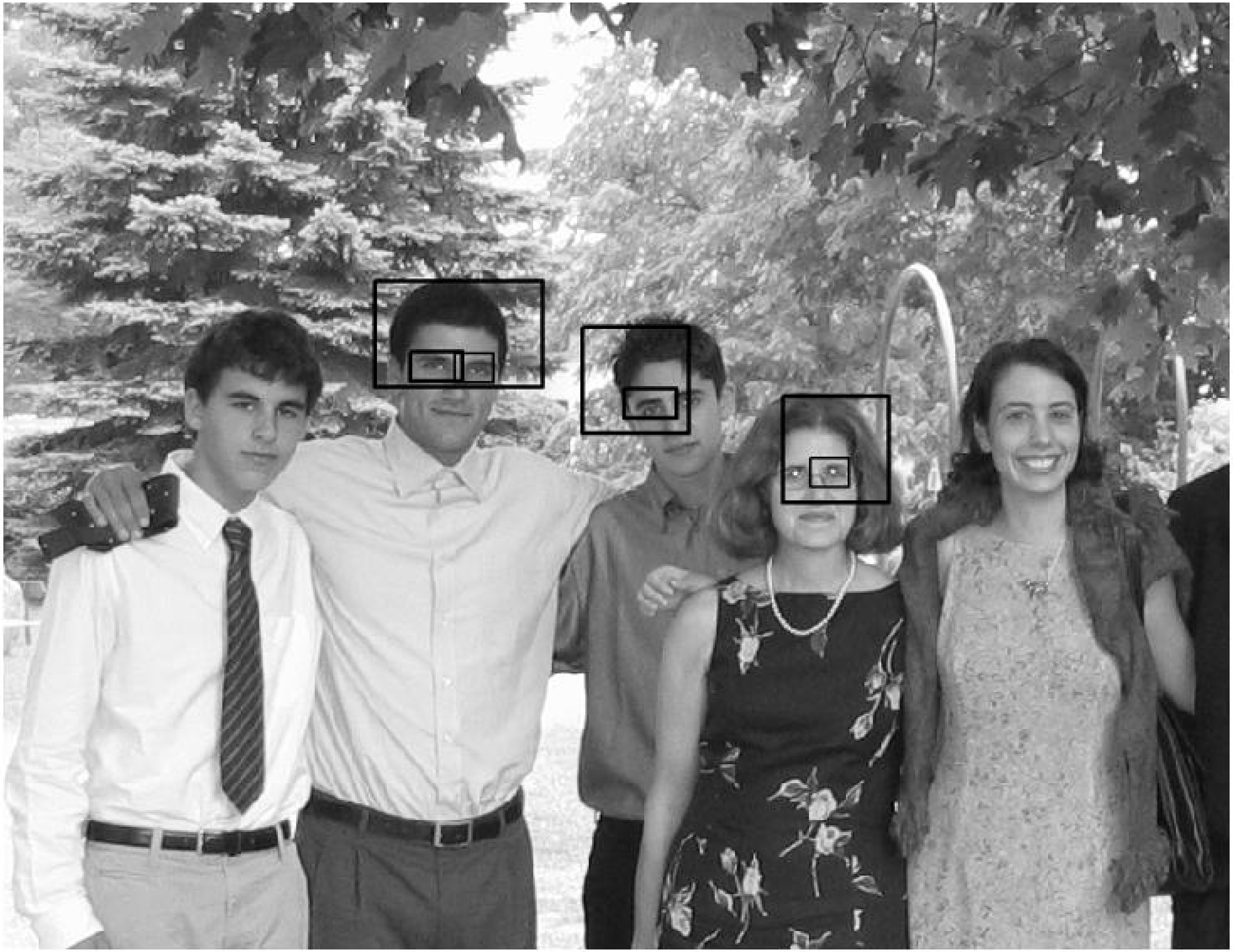
(b)
right–eye and left–eye templates

(c)
filtered with right–eye template

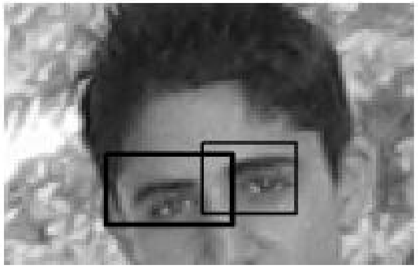


(d)
filtered with left–eye template

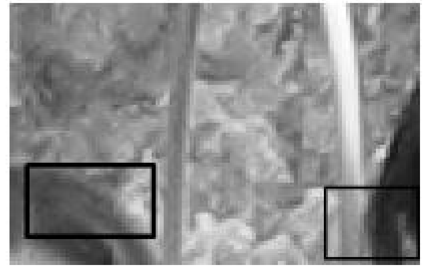
Computer experiments



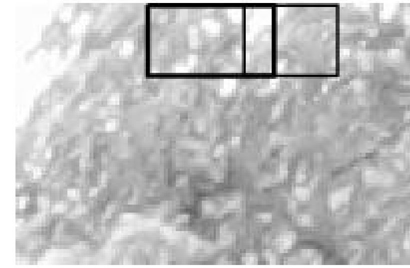
Computer experiments



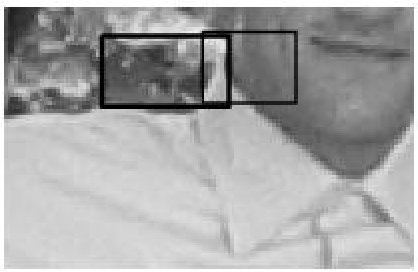
cell R activity: 0.62
cell L activity: 0.73
fci: 0.76



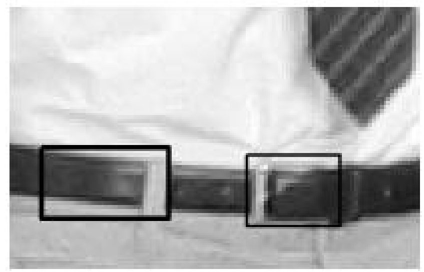
cell R activity: 0.59
cell L activity: 0.52
fci: 0.00



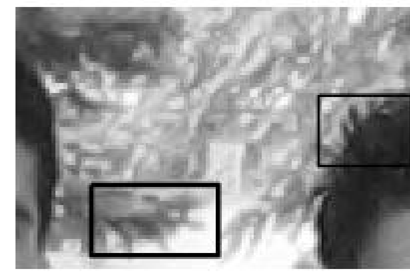
cell R activity: 0.39
cell L activity: 0.48
fci: 0.98



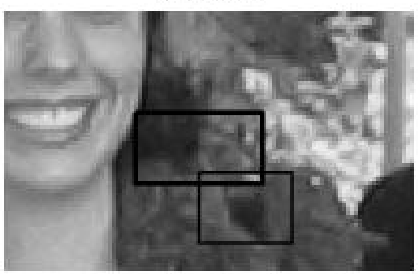
cell R activity: 0.59
cell L activity: 0.52
fci: 0.95



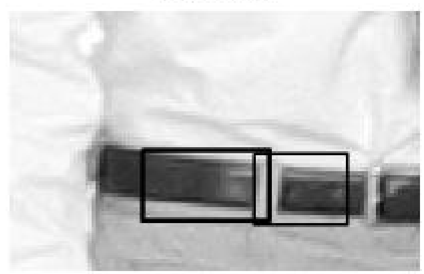
cell R activity: 0.71
cell L activity: 0.63
fci: 0.00



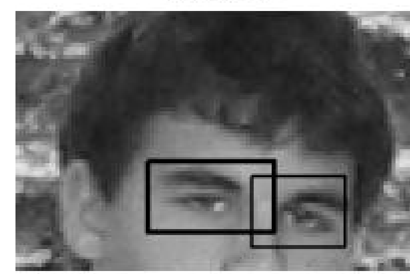
cell R activity: 0.68
cell L activity: 0.67
fci: 0.00



cell R activity: 0.63
cell L activity: 0.57
fci: 0.31

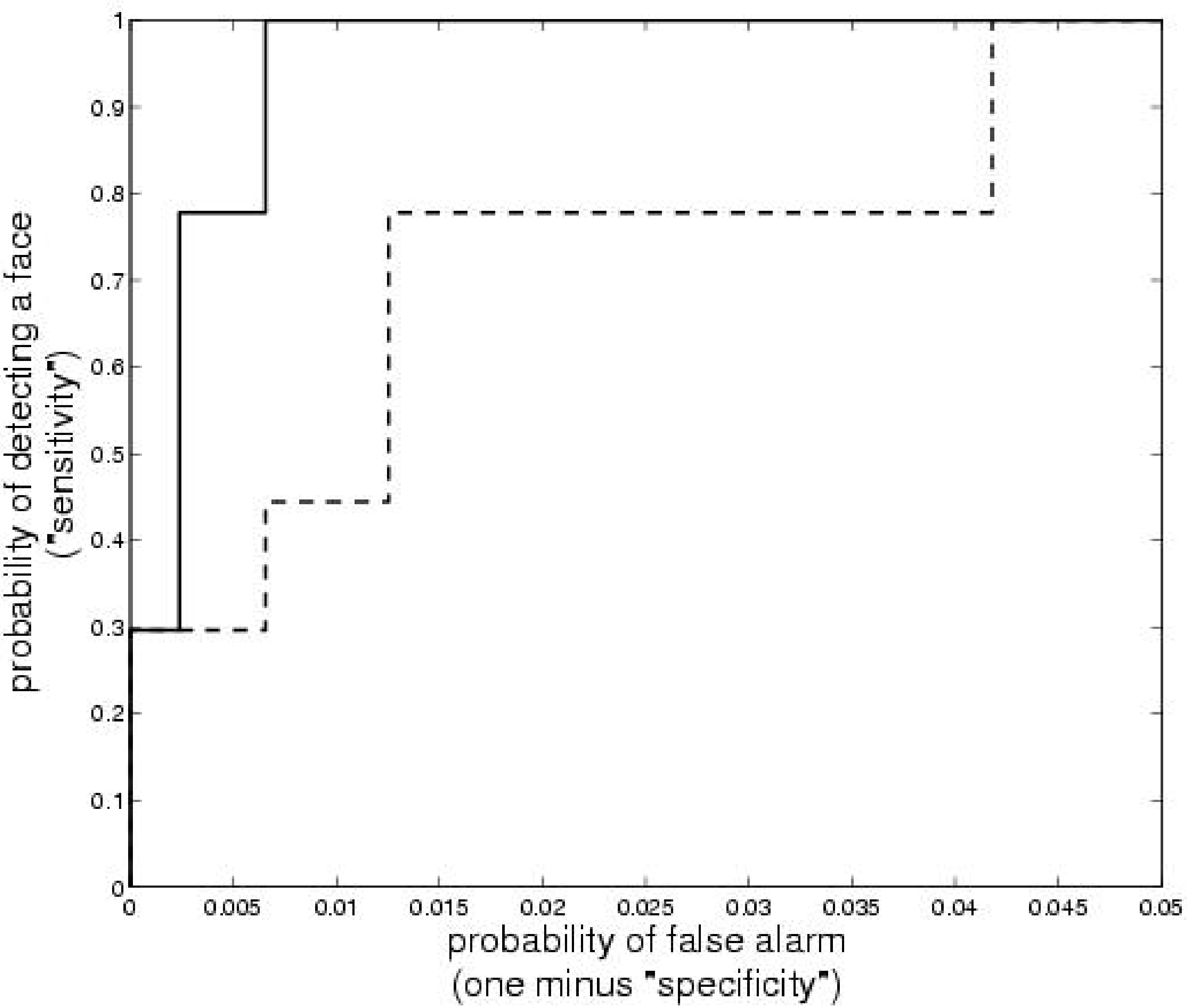


cell R activity: 0.64
cell L activity: 0.68
fci: 0.53



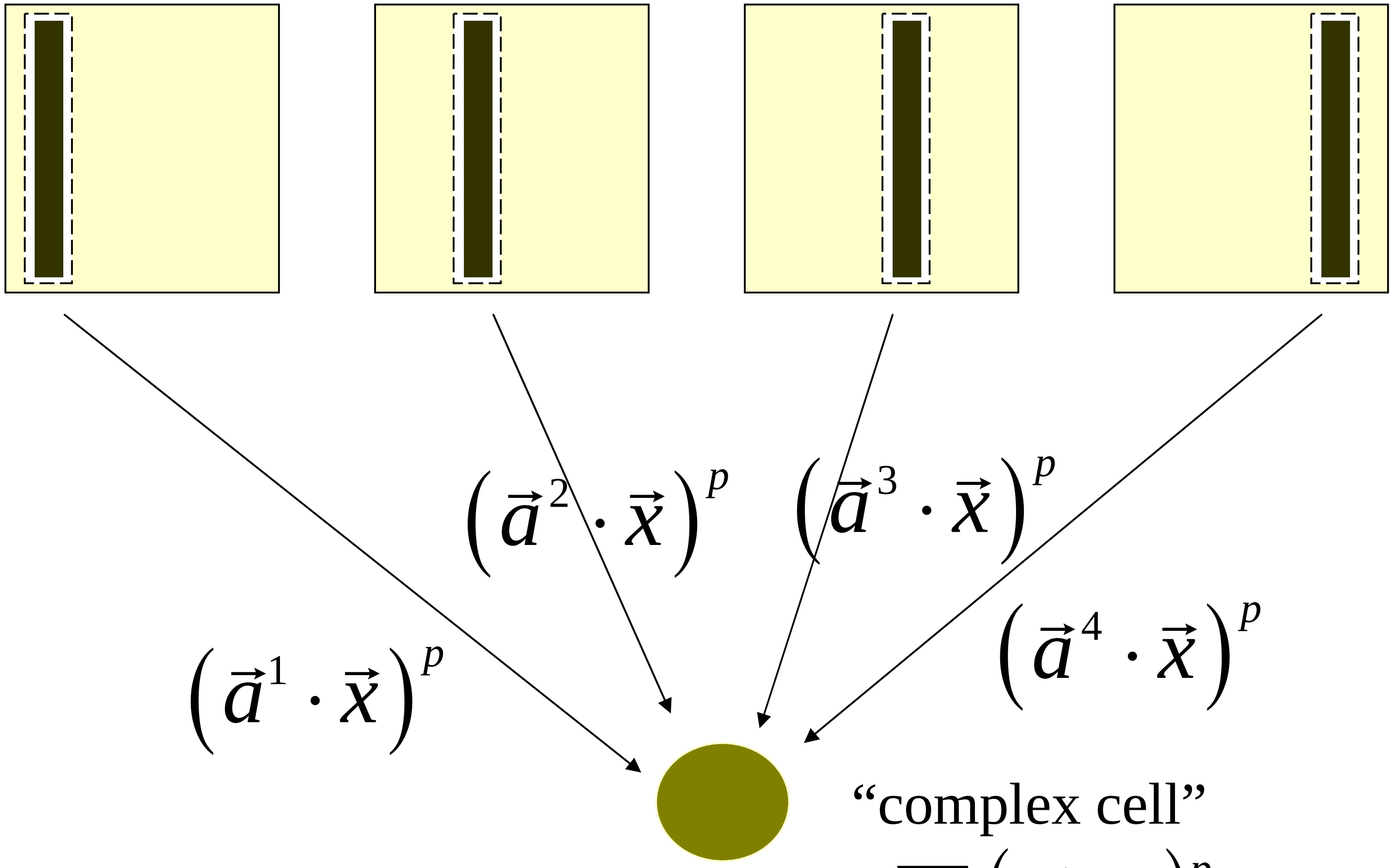
cell R activity: 0.58
cell L activity: 0.72
fci: 0.68

Computer experiments



Computer experiments (E. Bienenstock)

Integrate and fire model:



$$\left(\vec{a}^{1}\cdot\vec{x}\right)^{p} \quad \left(\vec{a}^{2}\cdot\vec{x}\right)^{p} \quad \left(\vec{a}^{3}\cdot\vec{x}\right)^{p} \quad \left(\vec{a}^{4}\cdot\vec{x}\right)^{p}$$

Each bar has 50 Poisson sources

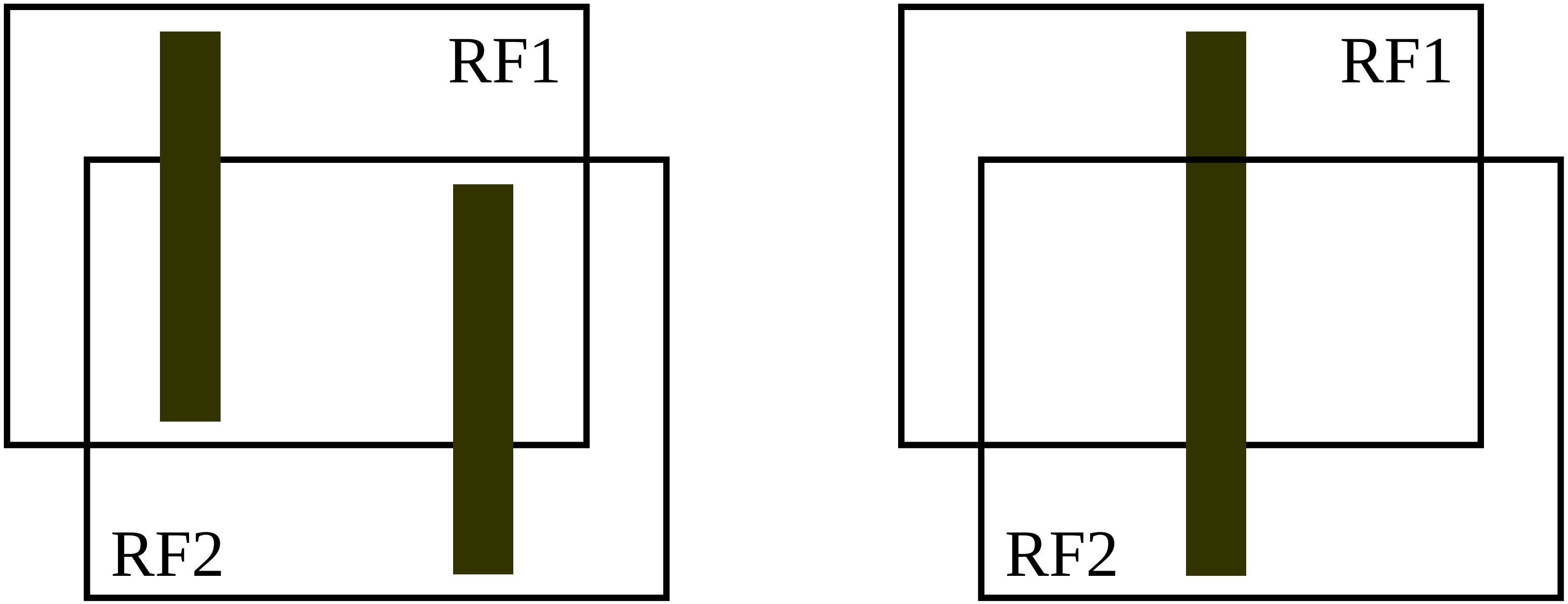
"complex cell"

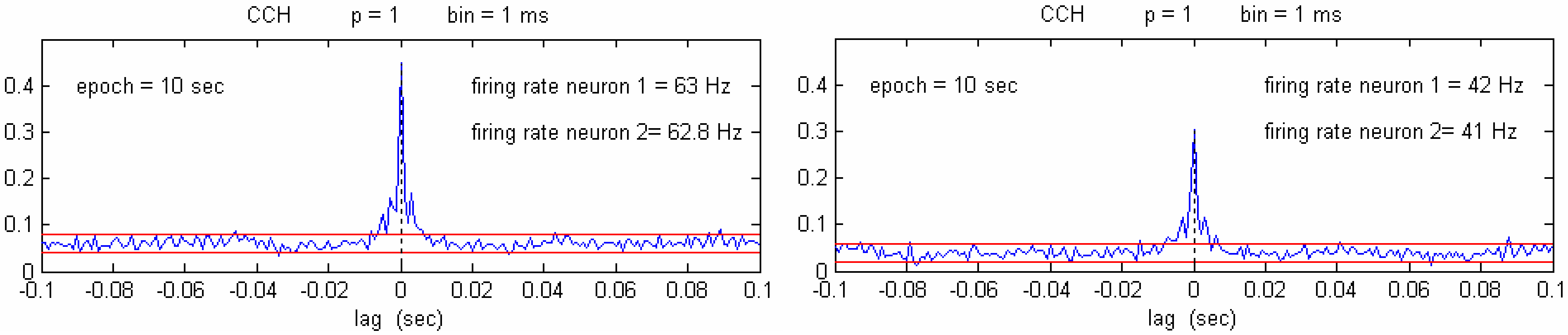
$$\sum_{\lambda\in\{1,2,3,4\}}\left(\vec{a}^{\lambda}\cdot\vec{x}\right)^{p}$$

Computer experiments

LINEAR (p=1)

Build two of these and study *functional vs anatomical* input:

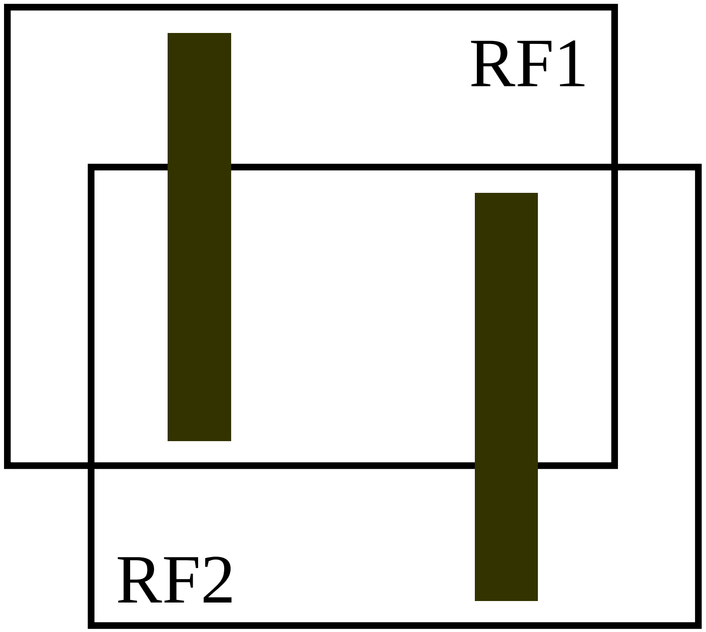


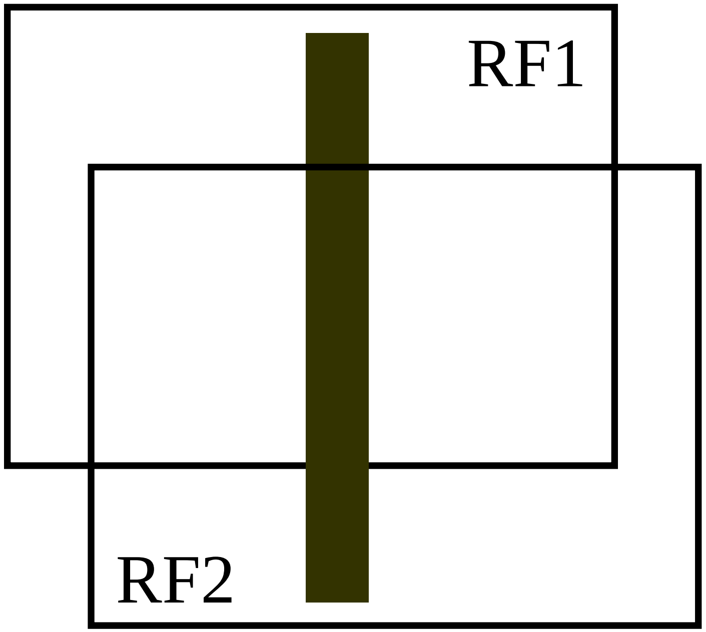


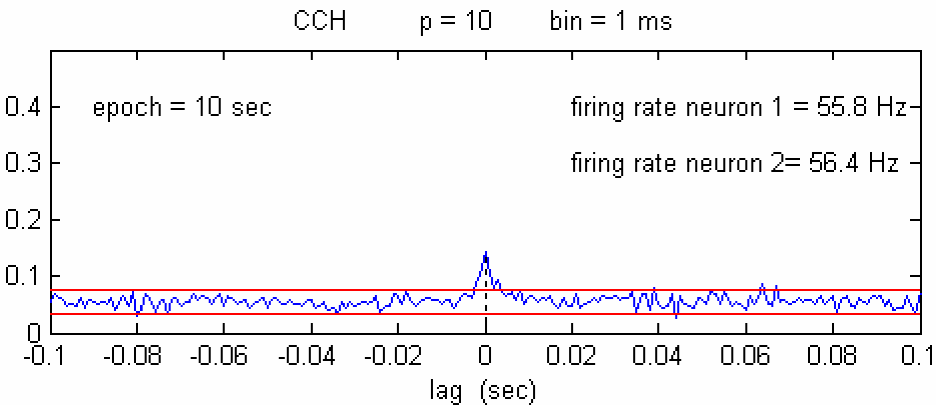
Computer experiments

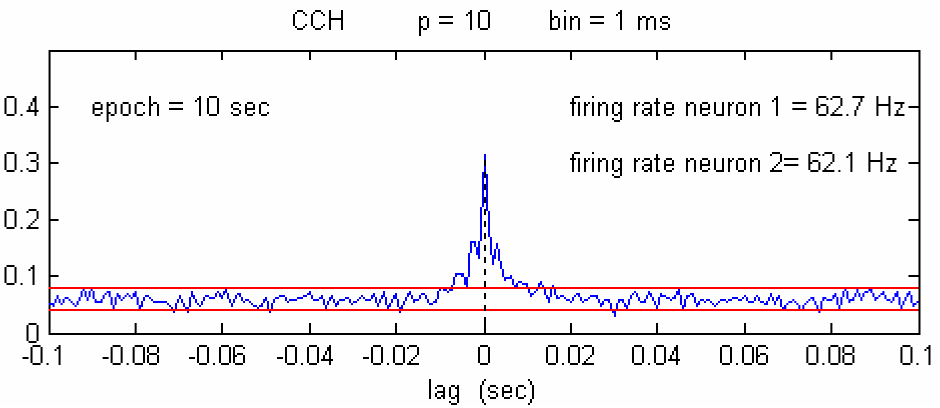
NONLINEAR (p=10)

Build two of these and study *functional vs anatomical* input:









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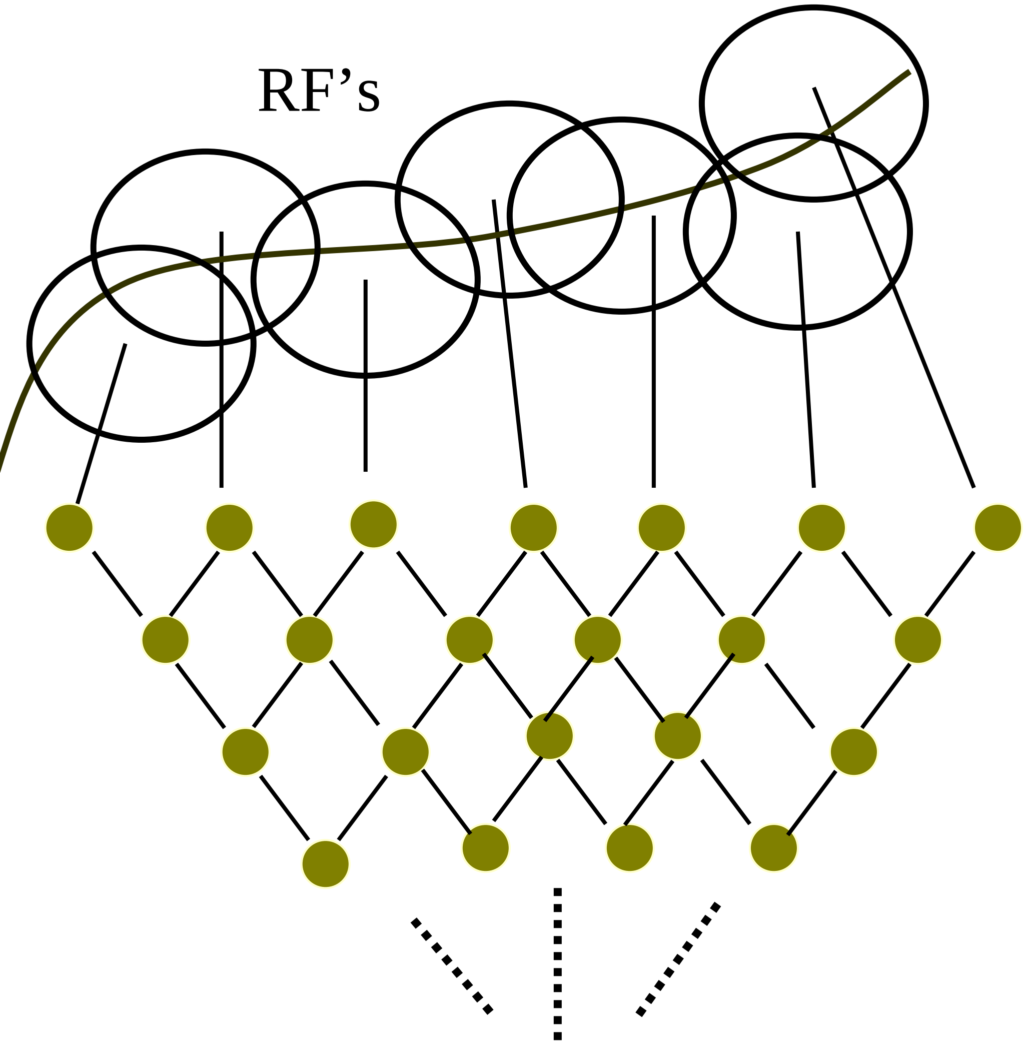

• divergence/convergence

bottom-up and top-down

(Abeles, Grossberg, Mumford, Ullman…)

• temporary topological structure

(von der Malsburg)

• local & partial synchronies

Thanks to

- Elie Bienenstock
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- David Shienberg

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